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Pollution and Global Health – An Agenda for Prevention

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Summary: Pollution is a major, overlooked, global health threat that was responsible in 2015 for an estimated 9 million deaths and great economic losses. To end neglect of pollution and advance prevention of pollution-related disease, we formed the *Lancet* Commission on Pollution and Health. Despite recent gains in understanding of pollution and its health effects, this Commission noted that large gaps in knowledge remain. To close these gaps and guide prevention, the Commission made research recommendations and proposed creation of a Global Observatory on Pollution and Health. We posit that successful pollution research will be translational and based on transdisciplinary collaborations among exposure science, epidemiology, data science, engineering, health policy, and economics. We envision that the Global Observatory on Pollution and Health will be a multinational consortium based at Boston College and the Harvard T.H. Chan School of Public Health that will aggregate, geocode, and archive data on pollution and pollution-related disease; analyze these data to discern trends, geographic patterns, and opportunities for intervention; and make its findings available to policymakers, the media, and the global public to catalyze research, inform policy, and assist cities and countries to target pollution, track progress, and save lives. https://doi.org/10.1289/EHP3141

Background

Pollution is a grave threat to planetary health. Like climate change (McMichael 2017), biodiversity loss, ocean acidification, desertification, and depletion of the world's fresh water supply, pollution destabilizes the earth's support systems and endangers the continuing survival of human societies (McMichael 2017; Rockström et al. 2009; Steffen et al. 2015; Whitmee et al. 2015). Pollution, especially pollution caused by industrial emissions, vehicular exhausts, and toxic chemicals, has increased in the past 100 y, with greatest increases reported in rapidly developing low- and middle-income countries (Lelieveld et al. 2015). Children are exquisitely vulnerable to pollution (Suk et al. 2006).

Pollution has been neglected in the international development and global health agendas as well as in the planning strategies of many countries. The foreign aid budgets of the European Commission, the U.S. Agency for International Development, and bilateral development agencies direct only meager resources to control of pollution from industrial, automotive, and chemical sources and to prevention of the diseases caused by these forms of pollution (Greenberg et al. 2016; Nugent 2016). No major foundation has made pollution prevention its priority.

In 2015, several of the authors formed the Commission on Pollution and Health under the sponsorship of *The Lancet* (Landrigan et al. 2017). The Commission conducted its work over a 2-y period and published its findings in October 2017 (Landrigan et al. 2017). The Commission's goals were to raise awareness of pollution's magnitude, end neglect of pollution-related disease, and mobilize the resources, the political leadership, and the civic will needed to control pollution and prevent pollution-related disease.

The Commission was highly interdisciplinary and included physicians, epidemiologists, exposure scientists, lawyers, policy analysts, political scientists, a former head of state, a princess, engineers, and economists. The decision to include economics and political science was modeled on the pathbreaking Stern Review on Climate Change (Stern 2007), which examined the economic costs of climate change and projected that, without intervention, these losses will consume 5% or more of global economic output. By reframing climate change as an economic challenge, the Stern Review moved the issue to center stage of international policy development and was a powerful catalyst to action.

To achieve its goals, the Commission adopted a four-part strategy:

1. Gather, combine, and analyze data on the global burden of disease, disability, and premature death attributable to all forms of pollution from the Institute for Health Metrics and Evaluation (Forouzanfar 2016; Kassebaum et al. 2016), the World Health Organization (WHO) (WHO 2016a, 2016b, 2016c, 2017a, 2017b), and Pure Earth (Pure Earth 2018).
2. Develop robust new estimates of the economic costs of pollution-related disease and death.
3. Elucidate the interconnections between pollution, poverty, and injustice and advance the argument that pollution is a violation of human rights.
4. Examine prospects and pathways for control of pollution and prevention of pollution-related disease.

Discussion

The Commission found that all forms of pollution were responsible in 2015 for an estimated 9 million premature deaths—16% of all deaths worldwide—as well as for 268 million disability-adjusted life-years (DALYs). Pollution is thus the world's largest

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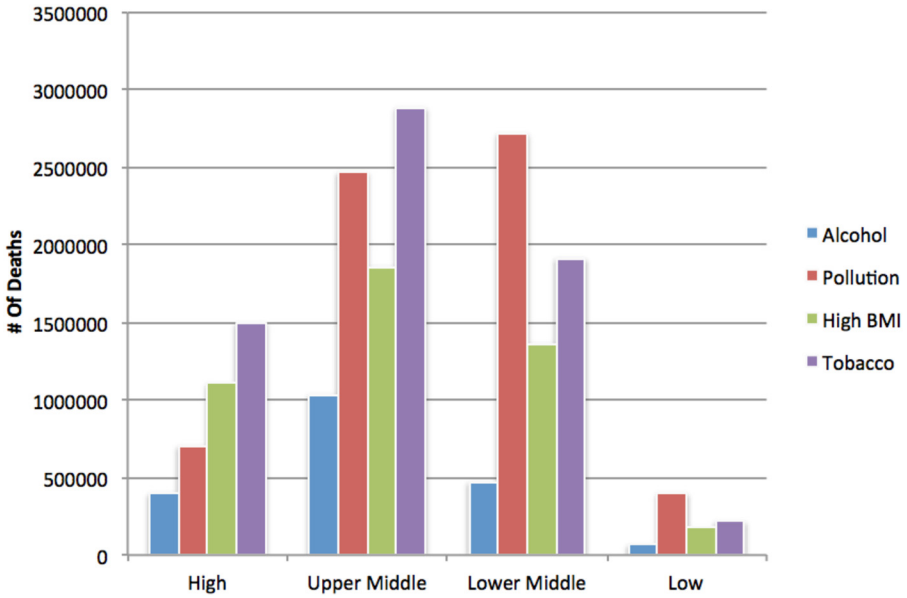

Figure 1. Global noncommunicable disease (NCD) deaths by risk factor and income group, 2015. Note: Adapted from Fuller et al. 2018. Permission for reproduction granted by *Lancet Planetary Health*.

environmental cause of disease and premature death (Landrigan et al. 2017).

The majority—71%—of the deaths attributed to pollution are caused by noncommunicable diseases (NCD). The impact of pollution on NCD mortality varies by national income (Figure 1) (Fuller et al. 2018). In high-income countries, where many of the unhealthiest forms of pollution have been controlled, behavioral and metabolic risk factors are the major causes of NCD mortality and overshadow the impacts of pollution. However, in upper-middle-income countries, pollution and behavioral risk factors are of approximately equal importance in NCD causation, and in lower-middle- and low-income countries, pollution is the predominant risk factor for NCD mortality.

The Commission considered chemical pollution to be a great and growing global threat. The threat of chemical pollution is especially high in low- and middle-income countries, where 70% of chemical manufacture now occurs and public health protections are often scant. An estimated 140,000 new chemicals and pesticides have been invented since 1950, and many have become widely disseminated in the environment (Landrigan and Goldman 2011; Prüss-Ustün et al. 2011). Human exposure is nearly universal (CDC 2018).

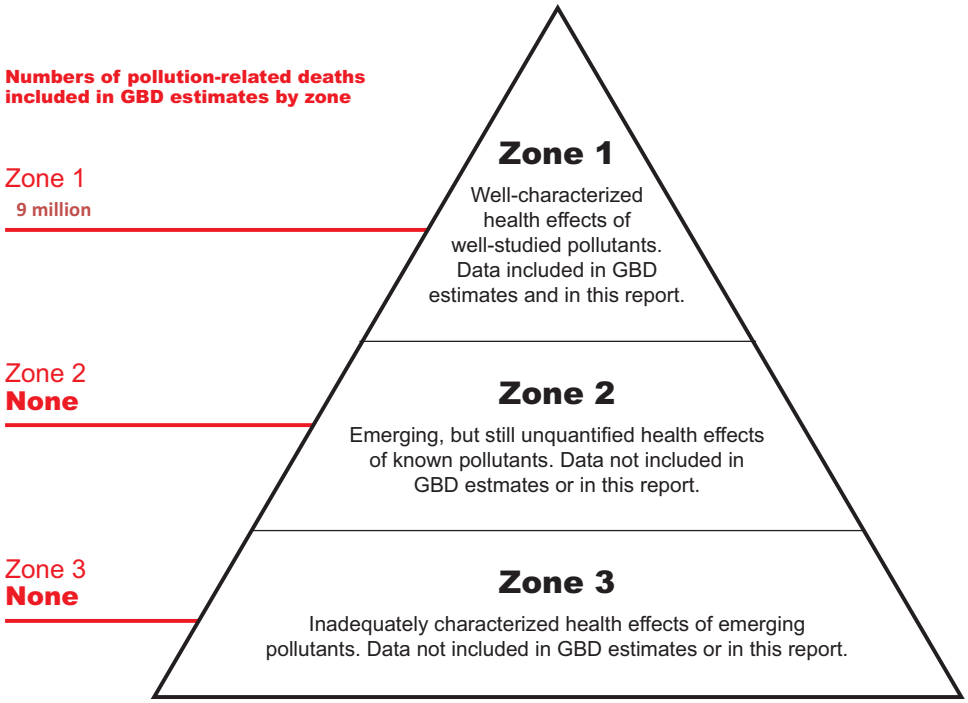

Figure 2. The pollutome (based on 2015 data). Note: GBD, Global Burden of Disease. Adapted from Landrigan et al. 2017. Permission for reproduction granted by *The Lancet*.

Table 1. A Research agenda for pollution control and disease prevention.

Agenda items	References
Health-Related Research	
Define and quantify the burden of neurodegenerative disease in adults that may be attributable to PM2.5 air pollution	Kioumourtzoglou et al. 2015; Heusinkveld et al. 2016; Cacciottolo et al. 2017
Define and quantify the burden of neurodevelopmental disabilities in children such as cognitive impairment ADHD and autism that may be attributable to PM2.5 pollution or to traffic-related air pollution	Perera et al. 2014; Volk et al. 2013; Casanova et al. 2016
Define and quantify the burden of diabetes that may be attributable to PM2.5 air pollution	Meo et al. 2015
Define and quantify the burden of chronic kidney disease that may be attributable to PM2.5 air pollution	Bowe et al. 2018
Define and quantify the burden of preterm birth and low birth weight attributable to PM2.5 air pollution	Ha et al. 2017; Cacciottolo et al. 2017; Malley et al. 2017
Better quantify the burden of disease and premature death caused by lead at lower blood lead levels in light of recent data linking low levels of lead in blood with increases in all-cause mortality and cardiovascular disease mortality	Lanphear et al. 2018
Better quantify the burden of disease caused by mercury	Ha et al. 2017
Better quantify the burden of disease caused by arsenic	Wasserman et al. 2016
Discover and quantify health effects associated with new and emerging chemical pollutants, such as developmental neurotoxicants, (Grandjean and Landrigan 2014) endocrine disruptors, (Bergman et al., 2013; Gore et al., 2015) chemical herbicides, newer classes of insecticides such as the neonicotinoids, and pharmaceutical wastes. (Petrie et al. 2015)	Grandjean and Landrigan 2014 (developmental neurotoxicants); Bergman et al. 2013; Gore et al. 2015 (endocrine disruptors); Petrie et al. 2015 (pharmaceutical wastes)
Develop new methodologies to improve quantification of the burden of disease and the loss of human capital that results from early-life exposures to neurodevelopmental toxicants	Bellinger 2012
Advocate for the inclusion of measures of pollution and its effects on health in the large cohort, precision medicine and other "Big Data" health projects currently in development	Hu et al. 2017
Research in exposure science	
Improve mapping of pollution exposures particularly in low-income and middle-income countries, using a combination of ground-based monitoring and satellite imaging.	Rice et al. 2018
Increase research into transboundary pollution	Lin et al. 2014
Undertake systematic surveys in multiple countries of levels of lead and other toxic chemicals in blood and urine. (CDC) Data from such surveys will provide a benchmark to measurer future progress toward pollution control	
Establish umbilical cord blood banks in multiple countries to examine prenatal and perinatal exposures to lead and other developmental neurotoxicants	Arbuckle 2010
Support the development, application and networking of new technologies such as lab-on-a-chip apps for smart phones for personal and/or area sampling of pollutant exposures in low-resource settings	Dragone et al. 2017
Undertake source apportionment studies to identify and prioritize pollution sources	National Academy of Sciences 2012
Better define pathways of pollutant exposure in different countries and in different age groups	National Academy of Sciences 2012
Economic research	
Improve estimates of the morbidity costs of pollution	Landrigan et al. 2017
Improve estimates of the non-health benefits of reducing pollution	Landrigan et al. 2017
Quantify the health and economic benefits of interventions against pollution in relation to the costs of those interventions	Landrigan et al. 2017
Policy research	
Link pollution sources within countries with relevant government ministries and policies and to efforts supporting each country's commitment to the U.N.'s Sustainable Development Goals (SDGs)	United Nations 2017
Identify health as well as non-health sectoral targets for education on the costs to health and economies of pollution and the benefits of prevention-oriented policies and interventions	Galvão et al. 2016
Track progress on policy changes and resulting impacts on pollution	Watts et al. 2015
Research on pollution and vulnerable populations	
Document and map the disproportionate effects of pollution upon the poor, women, and girls	Sommer et al. 2016
Quantify the disproportionate exposure of indigenous peoples and their communities to pollution and use the information gained from this research to guide protection of indigenous peoples	Thomas-Muller 2008
Improve assessment of workers' exposure to known occupational carcinogens such as asbestos	
Research within cities and countries	
Identify and prioritize the pollution sources in cities that have the largest impacts on human health	Pure Earth 2018
Develop city- and country-wide exposure data for toxic chemical pollutants such as lead, cadmium, mercury, asbestos and industrial pollutants	National Academy of Sciences 2012
Evaluate economic costs and benefits of locally based interventions against pollution	Landrigan et al. 2017

A key message of the *Lancet* Commission on Pollution and Health is that pollution is preventable. The Commission noted that many countries, especially high-income and some upper-middle-income countries have developed robust, cost-effective, and politically viable pollution-control strategies based on law, policy, science, and technology (U.S. EPA 2011; Samet et al., 2017; Suk et al. 2018). The Commission expressed the view that pollution- control strategies that have proven successful in high-income and middle-income countries are ready to be taken off-the- shelf, brought to global scale, and applied in cities and countries at every level of income (Landrigan et al. 2017).

The Commission identified substantial gaps in knowledge about pollution and noted that these gaps result in underestimation of pollution's contribution to the global burden of disease while also impeding prevention (Landrigan et al. 2017). To create a framework for organizing knowledge about pollution and prioritizing research and intervention, the Commission developed the concept of the pollutome. Because scientific knowledge about pollution's effects on health and contributions to the global burden of disease varies by pollutant and by health outcome, the Commission divided the pollutome into three zones (Figure 2).

Future Directions in Pollution Research

To address gaps in knowledge about pollution and its effects on human health, the Commission called for an expanded pollution research agenda. Transdisciplinary research in multiple areas, including exposure science, epidemiology, data science, engineering, economics, law, and health policy, will be needed to close gaps in knowledge about pollution, its health effects, its contributions to the global burden of disease, and its economic consequences. In Table 1, the authors propose high-priority research topics based on our judgment that research on these topics advance scientific understanding of pollution and its effects on health and provide a science-based blueprint for control of pollution and prevention of pollution-related disease (Table 1).

To track pollution and pollution-related disease in cities and countries around the world, monitor progress toward prevention, and generate hypotheses for further research, the Commission recommended creation of a Global Observatory on Pollution and Health. Following is our vision for the objectives, structure, and prioritized research agenda for a Global Observatory on Pollution and Health.

We envision that the Global Observatory on Pollution and Health will be a new transnational, multidisciplinary collaboration that continues the work of *The Lancet* Commission on Pollution and Health (Landrigan et al. 2017). The core mission of the Observatory will be to aggregate, analyze, archive, and disseminate data on pollution and pollution-related disease in cities and countries around the world. The Observatory will be modeled on the disease surveillance programs of the Centers for Disease Control and Prevention (Langmuir 1963).

The Observatory will examine trends and patterns of pollution and provide early warnings of emerging problems. It will make carefully curated, validated information on pollution and pollution-related disease widely available to researchers, policy makers, civil society, the media, and the global public. The intent is that these data will generate hypotheses that guide research; inform the development of public policy; educate civil society and the media; and assist cities and countries to identify their worst forms of pollution, prioritize interventions, and track progress toward pollution control. The Observatory will highlight and disseminate information on advances and best practices in pollution control and disease prevention.

The Observatory will place strong emphasis on ensuring the rigor and validity of the data included in its analyses. It will model its data-assurance program on that developed by the Institute for Health Metrics and Evaluation (IHME).

Sources from which the Global Observatory on Pollution and Health plans to assemble data could include:

- The annual Global Burden of Disease report and disease–risk factor reports produced by the Institute for Health Metrics and Evaluation at the University of Washington.
- WHO reports.
- World Bank Country Environmental Analyses.
- Google Earth.
- Data from the U.S. Geological Survey on mineral production, import and use by country.
- Data from CDC's National Biomonitoring Program to track exposures to pollutants.
- Customs records to track imports into countries of hazardous materials, such as asbestos and banned pesticides.
- Data from the Secretariats of the Rotterdam and Basel Conventions.
- Satellite monitoring to track toxic emissions to air, and possibly water (Rice et al. 2018).
- Country-level surveys (Ericson et al. 2013; Steckling et al. 2017) to identify hazardous waste in soil, groundwater, and surface water and to provide a basis for developing estimates of the size and demographic characteristics of exposed populations.
- Country-level estimates of lead use and exposure.

The Global Observatory on Pollution and Health will rely on a series of validated metrics to track pollution and disease. The precise metrics to be followed are still under consideration but could include data on levels of key pollutants in air, water, and soil, country-by-country and regionally; detailed country-by-country statistics on burden of disease and premature death by pollution risk factor; country- or city-specific data on the status of regulations against each type of pollution; country-level data on levels of investment into research on pollution and pollution-related disease, which can be examined by source of investment; and a database on the cost efficacy of interventions against pollution. This metrics-based approach to tracking pollution and pollution-related disease is modeled on that of the *Lancet* Countdown on Climate Change, which is tracking progress globally and country by country in addressing global climate change (Watts et al. 2015).

Mapping will be an important function of the Global Observatory on Pollution and Health. Data collected from various sources will be geocoded and entered into a multilayered Geographic Information System (GIS) model for each country. This approach will have the following benefits:

- By correlating data on pollution sources with census data, maps will facilitate identification of exposed populations.
- Geocoded maps will permit the addition of multiple layers of information as new data sources on pollution are discovered or created.
- Maps are an effective tool for translating scientific information to the public, even in areas of low literacy, and in building political will to control pollution, because they can clearly show that pollution is a local problem.
- Maps facilitate development of data on the economic costs of pollution because they make it possible to visualize the geographic extent of ecological damage and the size of affected populations.
- Pollution maps can be integrated with disease maps and economic maps to discern patterns in need of further investigation.

The Global Observatory on Pollution and Health will headquartered in the Schiller Institute for Integrated Science and

Society at Boston College and based on collaboration between the Schiller Institute and the Center for Health and the Global Environment at the Harvard T.H. Chan School of Public Health. It will plan to work with a series of carefully chosen partners that could include the Institute for Health Metrics and Evaluation, WHO, U.N. Environment, the U.N. Development Program, the World Bank, the Planetary Health Alliance, the *Lancet* Countdown on Climate Change, the Consortium on Biodiversity and Health, the World Resources Institute's Global Resource Watch, the Icahn School of Medicine at Mount Sinai, Pure Earth, the Global Alliance on Health and Pollution (GAHP), the Global Air Pollution Observatory (GUAPO), and major universities, government agencies, and nongovernmental organizations around the world. In partnership with *The Lancet*, the Observatory would publish periodically updated information on global trends in pollution, pollution-related disease, and pollution control.

The Global Observatory on Pollution and Health will utilize a variety of media and data platforms to disseminate its findings to multiple audiences. In partnership with *The Lancet*, the Observatory plans to regularly publish updated information on global trends and patterns in pollution and pollution-related disease as well as on progress in pollution control. The Global Observatory on Pollution and Health will also produce a series of scientific reports and analyses on specific topics. These could include:

- Analyses of the effects of pollution on children's health and adolescent health.
- Analyses of the impact of pollution on cardiovascular disease and death.
- Analyses of the impact of pollution on cancer.
- Updated analyses of the global burden of disease due to various occupational toxicants and carcinogens such as asbestos.
- Updated analyses of the global burden of disease due to lead incorporating new data on the association between low-level exposure to lead and risk of death from cardiovascular disease (Lanphear et al. 2018).
- Updated analyses of the global burden of disease due to mercury based on data on mercury use, environmental contamination and exposure collected under the Minamata convention (Ha et al. 2017).
- Analyses of the loss of human capital caused by early-life exposures to developmental neurotoxicants.

To guide the development of pollution control and disease prevention policies internationally and within cities and countries, the Global Observatory on Pollution and Health will undertake and publish economic and policy analyses. Examples might include:

- Analyses of the burden of disease due to pollution in cities and countries that include options for pollution control and disease prevention.
- Source apportionment studies that analyze the amounts of pollution and the burden of disease due to various pollution sources in cities and countries. These studies are essential for identifying the pollution sources with most significant effects on human health and for prioritizing interventions.
- Country-level analyses of the burden of disease and loss of human capital attributable to various pollutants and all pollution in specific countries (or cities) and examine prospects for prevention.
- Economic analyses that examine the cost–benefit ratios of various interventions against pollution.

The *Lancet* Commission on Pollution and Health concludes that pollution is a winnable battle (Landrigan et al. 2017). The Commission offered the view that the key tools and technologies needed to control pollution in all countries have been developed and are ready today to be taken to global scale. The Commission opined that, with visionary international and country-level leadership, strong support from civil society, and sufficient resources, the worst forms of pollution could be controlled within a generation. The Global Observatory on Pollution and Health will provide the path forward.

References

Arbuckle TE. 2010. Maternal-infant biomonitoring of environmental chemicals: the epidemiologic challenges. Birth Defects Res Part A Clin Mol Teratol 88(10):931–937, PMID: 20706992, https://doi.org/10.1002/bdra.20694.

Bellinger DC. 2012. A strategy for comparing the contributions of environmental chemicals and other risk factors to neurodevelopment of children. Environ Health Perspect 120(4):501–507, PMID: 22182676, https://doi.org/10.1289/ehp.1104170.

Bergman A, Heindel JJ, Kasten T, Kidd KA, Jobling S, Neira M, et al. 2013. The impact of endocrine disruption: a consensus statement on the state of the science. Environ Health Perspect 121(4):a104–a106, PMID: 23548368, https://doi.org/10.1289/ehp.1205448.

Bowe B, Xie Y, Li T, Yan Y, Xian H, Al-Aly Z. 2018. Particulate matter air pollution and the risk of incident CKD and progression to ESRD. J Am Soc Nephrol. 29(1):218–230, PMID: 28935655, https://doi.org/10.1681/ASN.2017030253.

Cacciottolo M, Wang X, Driscoll I, Woodward N, Saffari A, Reyes J, et al. 2017. Particulate air pollutants, APOE alleles and their contributions to cognitive impairment in older women and to amyloidogenesis in experimental models. Transl Psychiatry 7(1):e1022, PMID: 28140404, https://doi.org/10.1038/tp.2016.280.

Casanova R, Wang X, Reyes J, Akita Y, Serre ML, Vizuete W, et al. 2016. A voxel-based morphometry study reveals local brain structural alterations associated with ambient fine particles in older women. Front Hum Neurosci 10:495, PMID: 27790103, https://doi.org/10.3389/fnhum.2016.00495.

CDC (Centers for Disease Control and Prevention). 2018. National Biomonitoring Program. https://www.cdc.gov/biomonitoring/ [accessed 8 March 2018].

Dragone R, Grasso G, Muccini M, Toffanin S. 2017. Portable bio/chemosensoristic devices: innovative systems for environmental health and food safety diagnostics. Front Public Health 5(5):80, PMID: 28529937, PMCID: PMC5418341, https://doi.org/10.3389/fpubh.2017.00080.

Ericson B, Caravanos J, Chatham-Stephens K, Landrigan P, Fuller R. 2013. Approaches to systematic assessment of environmental exposures posed at hazardous waste sites in the developing world: the Toxic Sites Identification Program. Environ Monit Assess 185(2):1755–1766, PMID: 22592783, https://doi.org/10.1007/s10661-012-2665-2.

Forouzanfar MH, Afshin A, Alexander LT, Anderson HR, Bhutta ZA, Biryukov S, et al. GBD 2015 Risk Factors Collaborators. 2016. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease. Lancet 388(10053):1659–1724, PMID: 27733284, https://doi.org/10.1016/S0140-6736(16)31679-8.

Fuller R, Rahona E, Fisher S, Caravanos J, Webb D, Kass D, et al. 2018. Pollution and non-communicable disease – time to end the neglect. Lancet Planetary Health 2(3):e96–e98, PMID: 29615229, https://doi.org/10.1016/S2542-5196(18)30020-2.

Galvão LA, Haby MM, Chapman E, Clark R, Câmara VM, Luiz RR, et al. 2016. The new United Nations approach to sustainable development post-2015: findings from four overviews of systematic reviews on interventions for sustainable development and health. Rev Panam Salud Publica 39(3):157–165, PMID: 27754525.

Gore AC, Chappell VA, Fenton SE, Flaws JA, Nadal A, Prins GS, et al. 2015. EDC-2: The Endocrine Society's second scientific statement on endocrine-disrupting chemicals. Endocr Rev 36(6):E1–E150, PMID: 26544531, https://doi.org/10.1210/er.2015-1010.

Grandjean P, Landrigan PJ. 2014. Neurobehavioural effects of developmental toxicity. Lancet Neurol 13(3):330–338, PMID: 24556010, https://doi.org/10.1016/S1474-4422(13)70278-3.

Greenberg H, Leeder SR, Raymond SU. 2016. And Why So Great a "No"?: The donor and academic communities' failure to confront global chronic disease. Glob Heart 11(4):381–385, PMID: 27938822, https://doi.org/10.1016/j.gheart.2016.10.018.

Ha E, Basu N, Bose-O'Reilly S, Dórea JG, McSorley E, Sakamoto M, et al. 2017. Current progress on understanding the impact of mercury on human health. Environ Res 152:419–433, PMID: 27444821, https://doi.org/10.1016/j.envres.2016.06.042.

Heusinkveld HJ, Wahle T, Campbell A, Westerink RHS, Tran L, Johnston H, et al. 2016. Neurodegenerative and neurological disorders by small inhaled particles. Neurotoxicology 56:94–106, PMID: 27448464, https://doi.org/10.1016/j.neuro.2016.07.007.

Hu H, Galea S, Rosella L, Henry D. 2017. Big data and population health: focusing on the health impacts of the social, physical, and economic environment. Epidemiology 28(6):759–762, PMID: 28682850, https://doi.org/10.1097/EDE.0000000000000711.

Kassebaum NJ, Arora M, Barber RM, Bhutta ZA, Brown J, Carter A, Casey DC, et al. 2016. Global, regional, and national disability-adjusted life-years (DALYs) for 315 diseases and injuries and healthy life expectancy (HALE), 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet 388 (10053):1603–1658, https://doi.org/10.1016/S0140-6736(16)31460-X.

Kioumourtzoglou M-A, Schwartz JD, Weisskopf MG, Melly SJ, Wang Y, Dominici F, et al. 2015. Long-term PM2.5 exposure and neurological hospital admissions in the Northeastern United States. Environ Health Perspect 124(1):23–29, PMID: 25978701, https://doi.org/10.1289/ehp.1408973.

Landrigan PJ, Fuller R, Acosta NJR, Adeyi O, Arnold R, Basu N, et al. 2017. The Lancet Commission on Pollution and Health. Lancet, PMID: 29056410, https://doi.org/10.1016/S0140-6736(17)32345-0.

Landrigan PJ, Goldman LR. 2011. Children's vulnerability to toxic chemicals: a challenge and opportunity to strengthen health and environmental policy. Health Aff (Millwood) 30(5):842–850, PMID: 21543423, https://doi.org/10.1377/hlthaff.2011.0151.

Langmuir AD. 1963. The surveillance of communicable diseases of national importance. N Engl J Med 268:182–192, PMID: 13928666, https://doi.org/10.1056/NEJM196301242680405.

Lanphear B, Rauch S, Auinger P, Allen R, Hornung RW. 2018. Low-level lead exposure and mortality in US adults: a population-based cohort study. Lancet Public Health 3(4):e177–e184, PMID: 29544878, https://doi.org/10.1016/S2468-2667(18)30025-2.

Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. 2015. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature 525(7569):367–371, PMID: 26381985, https://doi.org/10.1038/nature15371.

Lin J, Pan D, Davis SJ, Zhang Q, He K, Wang C, et al. 2014. China's international trade and air pollution in the United States. Proc Natl Acad Sci USA 111(5):1736–1741, PMID: 24449863, https://doi.org/10.1073/pnas.1312860111.

Malley CS, Kuylenstierna JCI, Vallack HW, Henze DK, Blencowe H, Ashmore MR. 2017. Preterm birth associated with maternal fine particulate matter exposure: a global, regional and national assessment. Environ Int 101:173–182, PMID: 28196630, https://doi.org/10.1016/j.envint.2017.01.023.

McMichael AJ. 2017. *Climate Change and the Health of Nations: Famines, Fevers, and the Fate of Populations*. London: Oxford University Press.

Meo SA, Memon AN, Sheikh SA, Rouq FA, Usmani AM, Hassan A, et al. 2015. Effect of environmental air pollution on type 2 diabetes mellitus. Eur Rev Med Pharmacol Sci 19(1):123–128, PMID: 25635985.

National Academy of Sciences. 2012. *Exposure Science in the 21st Century A Vision and a Strategy*. Washington: National Academy Press.

Nugent R. 2016. A chronology of global assistance funding for NCD. Glob Heart 11(4):371–374, PMID: 27938820, https://doi.org/10.1016/j.gheart.2016.10.027.

Perera FP, Chang H, Tang D, Roen EL, Herbstman J, Margolis A, et al. 2014. Early-life exposure to polycyclic aromatic hydrocarbons and ADHD behavior problems. PLoS ONE 9(11):e111670, PMID: 25372862, https://doi.org/10.1371/journal.pone.0111670.

Petrie B, Barden R, Kasprzyk-Hordern B. 2015. A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring. Water Res 72:3–27, PMID: 25267363, https://doi.org/10.1016/j.watres.2014.08.053.

Prüss-Ustün A, Vickers C, Haefliger P, Bertollini R. 2011. Knowns and unknowns on burden of disease due to chemicals: a systematic review. Environ Health 10:9, PMID: 21255392, https://doi.org/10.1186/1476-069X-10-9.

Pure Earth: Blacksmith Institute. Toxic Sites Identification Program (TSIP). 2018. http://www.pureearth.org/projects/toxic-sites-identification-program-tsip/ [accessed 8 March 2018].

Rice MB, Li W, Dorans KS, Wilker EH, Ljungman P, Gold DR, et al. 2018. Exposure to traffic emissions and fine particulate matter and computed tomography measures of the lung and airways. Epidemiology 29(3):333–341, PMID: 29384790, https://doi.org/10.1097/EDE.0000000000000809.

Rockström J, Steffen W, Noone K, Persson Å, Chapin IIIFS, Lambin EF, et al. 2009. A safe operating space for humanity. Nature 461(7263):472–475, PMID: 19779433, https://doi.org/10.1038/461472a.

Samet JM, Burke TA, Goldstein BD. 2017. The Trump Administration and the environment—heed the science. N Engl J Med 376(12):1182–1188, PMID: 28249122, https://doi.org/10.1056/NEJMms1615242.

Sommer M, Caruso BA, Sahin M, Calderon T, Cavill S, Mahon T, et al. 2016. A time for global action: addressing girls' menstrual hygiene management needs in schools. PLoS Med 13(2):e1001962, PMID: 26908274, https://doi.org/10.1371/journal.pmed.1001962.

Steckling N, Tobollik M, Plass D, Hornberg C, Ericson B, Fuller R, et al. 2017. Global burden of disease of mercury used in artisanal small-scale gold mining. Ann Glob Health 83(2):234–247, PMID: 28619398, https://doi.org/10.1016/j.aogh.2016.12.005.

Steffen W, Richardson K, Rockstrom J, Cornell SE, Fetzer I, Bennett EM, et al. 2015. Planetary boundaries: guiding human development on a changing planet. Science 347(6223):1259855–1259855, PMID: 25592418, https://doi.org/10.1126/science.1259855.

Stern NH. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.

Suk WA, Ahanchian H, Asante KA. 2006. Environmental pollution: an under-recognized threat to children's health, especially in low- and middle-income countries. Environ Health Perspect 124 (3):A41–A45.

Suk WA, Heacock ML, Trottier BA, Amolegbe SM, Avakian MD, Henry HF, et al. 2018. Assessing the economic and societal benefits of SRP-funded research. Environ Health Perspect 126(6):065002, PMID: 29916809, https://doi.org/10.1289/EHP353.4.

Thomas-Muller C. 2008. Tar sands: environmental justice, treaty rights and indigenous peoples. Can Dimens 42(2).

United Nations. 2017. Sustainable Development Knowledge Platform. Transforming our world: the 2030 agenda for sustainable development. https://sustainabledevelopment.un.org/post2015/transformingourworld [accessed 18 January 2017].

U.S. EPA (U.S. Environmental Protection Agency). 2011. Office of Air and Radiation. The Benefits and Costs of the Clean Air Act from 1990 to 2020. Washington, D.C.: U.S. EPA. https://www.epa.gov/sites/production/files/2015-07/documents/fullreport_rev_a.pdf [accessed 21 March 2018].

Volk HE, Lurmann F, Penfold B, Hertz-Picciotto I, McConnell R. 2013. Traffic-related air pollution, particulate matter, and autism. JAMA Psychiatry 70(1):71, PMID: 23404082, https://doi.org/10.1001/jamapsychiatry.2013.266.

Wasserman GA, Liu X, Parvez F, Factor-Litvak P, Kline J, Siddique AB, et al. 2016. Child intelligence and reductions in water arsenic and manganese: a two-year follow-up study in Bangladesh. Environ Health Perspect 124(7):1114–1120, PMID: 26713676, https://doi.org/10.1289/ehp.1509974.

Watts N, Adger WN, Agnolucci P, Blackstock J, Byass P, Cai W, et al. 2015. Health and climate change policy responses to protect public health. Lancet 386(10006):1861–1914, PMID: 26111439, https://doi.org/10.1016/S0140-6736(15)60854-6.

Whitmee S, Haines A, Beyrer C, Boltz F, Capon AG, de Souza Dias BF, et al. 2015. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet 386(10007):1973–2028, PMID: 26188744, https://doi.org/10.1016/S0140-6736(15)60901-1.

WHO (World Health Organization). 2016a. Ambient air pollution: a global assessment of exposure and burden of disease. http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf?ua=1 [accessed 8 March 2018].

WHO. 2016b. Lead poisoning and health. http://www.who.int/mediacentre/factsheets/fs379/en/ [accessed 8 March 2018].

WHO. 2016c. International Programme on Chemical Safety. The public health impact of chemicals: knowns and unknowns. http://apps.who.int/iris/bitstream/10665/206553/1/WHO_FWC_PHE_EPE_16.01_eng.pdf [accessed 8 March 2018].

WHO. 2017a. WHO global urban ambient air pollution database. http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/ [accessed 8 March 2018].

WHO. 2017b. Inheriting a sustainable world? Atlas on children's health and the environment. Geneva: World Health Organization. http://www.who.int/ceh/publications/inheriting-a-sustainable-world/en/ [accessed 8 March 2018].